Aluminum was detected in all 12 storm inflow samples, the average concentration being 1,470 μg/L (1.47 mg/L). Total aluminum data for 200 and 100-foot swale configurations are presented in Figure 5-16 and Figure 5-17.

Aluminum removal averaged 63 percent (SD=17 percent) for the 200-foot swale and 16 percent (SD=78 percent) for the 100-foot configuration. However, if the April 29 storm is excluded, the removal of Al for the 100-foot configuration would be 27 percent.

Dissolved aluminum in the stormwater inflow samples averaged 10 percent, with winter storms carrying less dissolved aluminum than summer storms (4 percent versus 15 percent). Percent removals of the dissolved fraction of the aluminum was negative for both swale configurations.

Nutrients

Inorganic non-metal nutrients including phosphorus and nitrogen are frequently found in stormwater runoff from urbanized watersheds. There are numerous sources for these nutrients, such as detergents, fertilizers, clay soils, decaying vegetation, and pet waste. In general, phosphorus is the limiting nutrient for most freshwater lakes in the Puget Sound area, and can stimulate nuisance algae blooms if present in excess amounts.

Phosphorus. In natural waters, most phosphorus (P) is found combined with oxygen as a phosphate, including ortho phosphate, organically bound phosphates, and condensed phosphate (American Public Health Association, 1985). Three types of phosphorus were monitored for this study: Total phosphorus (TP), ortho phosphate (ortho-P), and bio-available phosphorus (BAP). Ortho-P is predominantly dissolved, and readily available for uptake by plants and algae. BAP is a measure that includes both the ortho-P as well as that portion of the particulate P extractable with sodium hydroxide (Butkus, 1988). Good correlation was found between BAP concentrations and algae blooms in Lake Sammamish (Butkus, 1988).

The USEPA suggests that P loadings be limited to maintain lake water quality. Loadings to oligotrophic freshwater lakes of between 0.10 to 0.50 $g/m^2/year$ are suggested for lakes from 1 to 25 meters in depth (USEPA, 1986). USEPA also recommends that total P not exceed 0.05 mg/L in any stream at the point where it enters a lake or reservoir, nor more than 0.025 mg/L within the lake or reservoir (Ibid).

The average concentration of TP in the inflow for all 12 storm events was 0.15 mg/L, with a range between 0.015 and 0.34 mg/L. Ortho-P in the storm inflows averaged 0.02 mg/L, and BAP averaged 0.045 mg/L. Total phosphorus data for 200 and 100-foot swale configurations are presented in Figures 5-18 and 5-19.

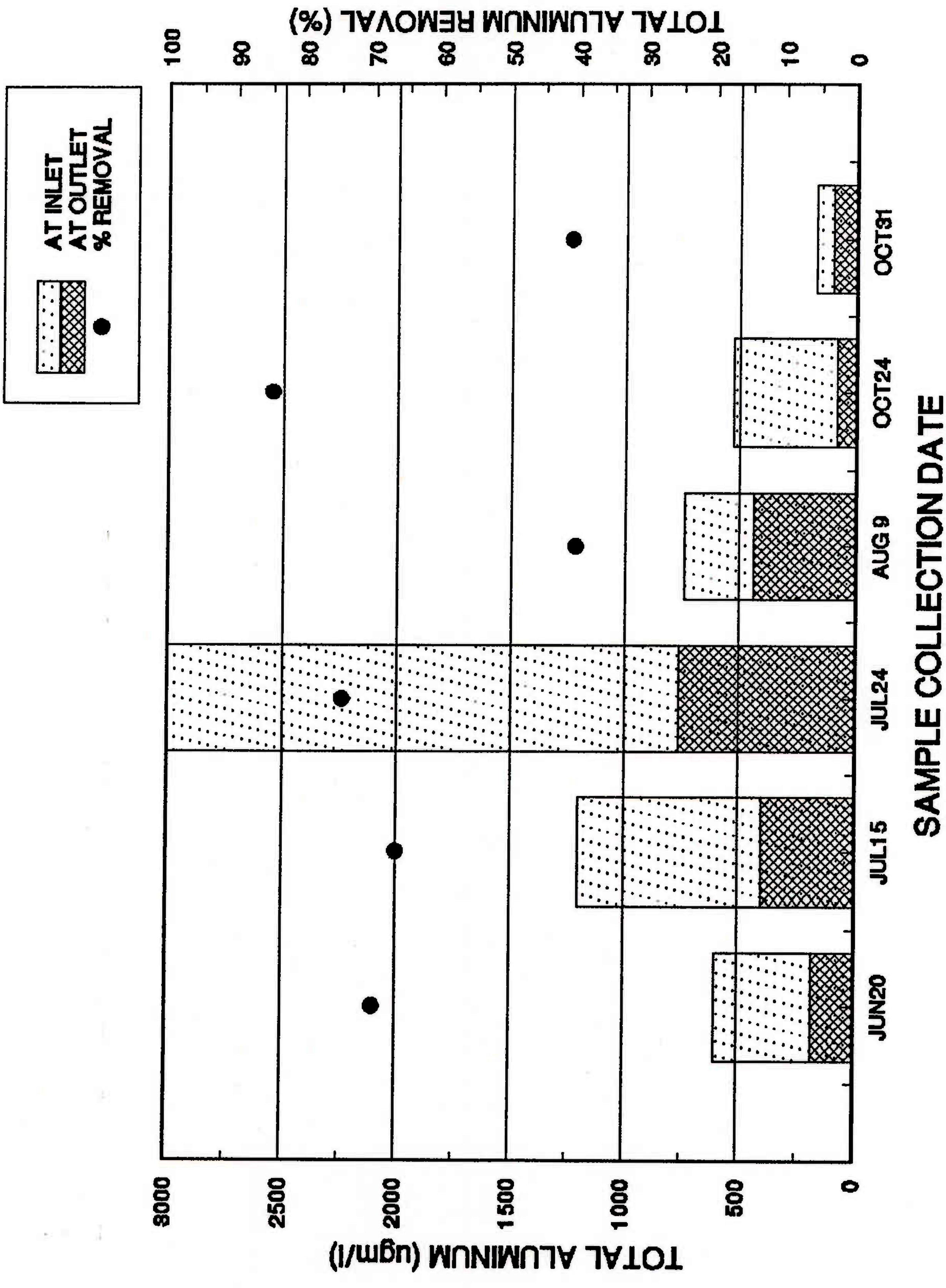

Figure 5-16. Total Aluminum Data, 200-Foot Length

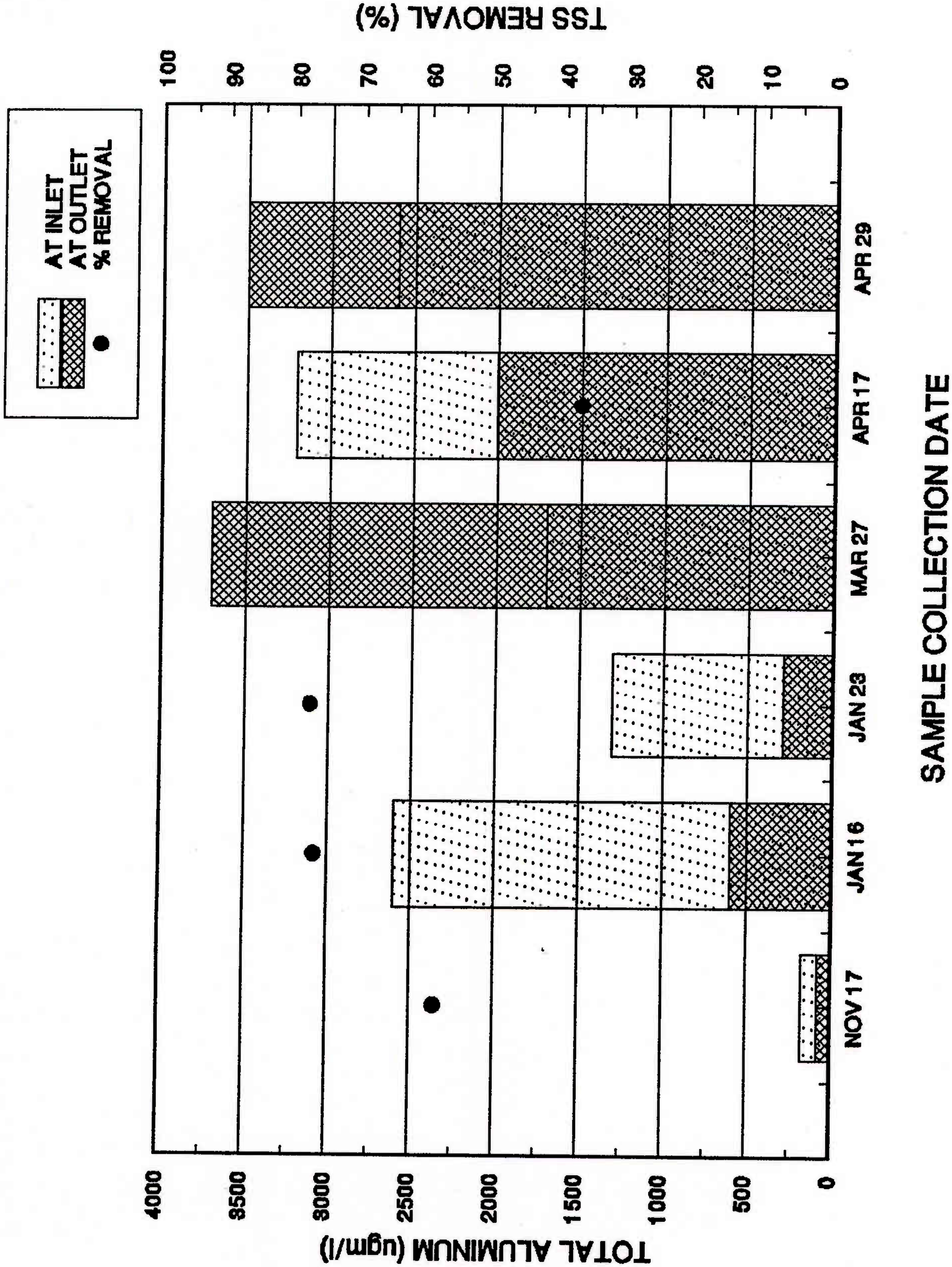

Figure 5-17. Total Aluminum Data, 100-Foot Length

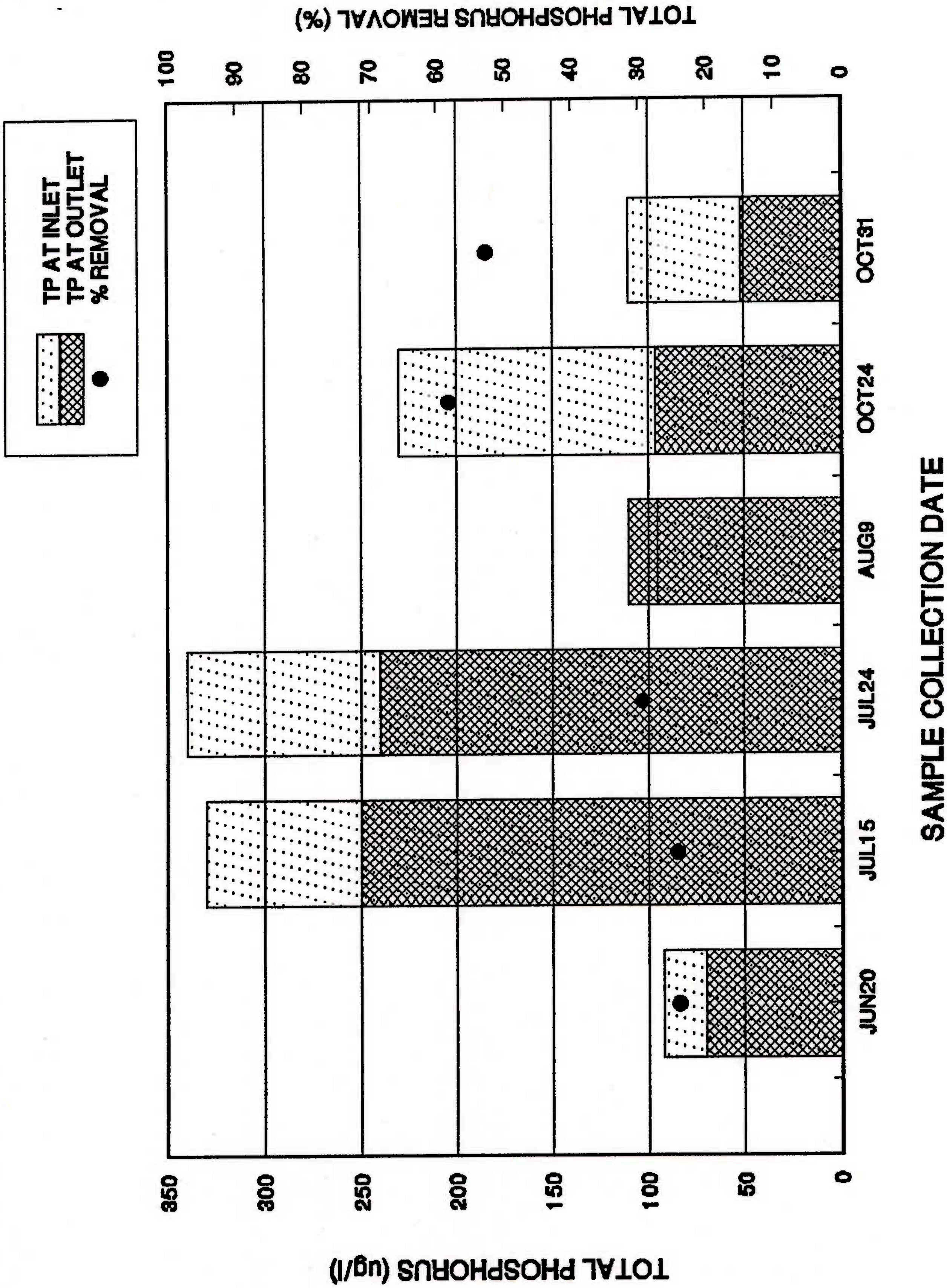

Figure 5-18. Total Phosphorus Data, 200-Foot Length

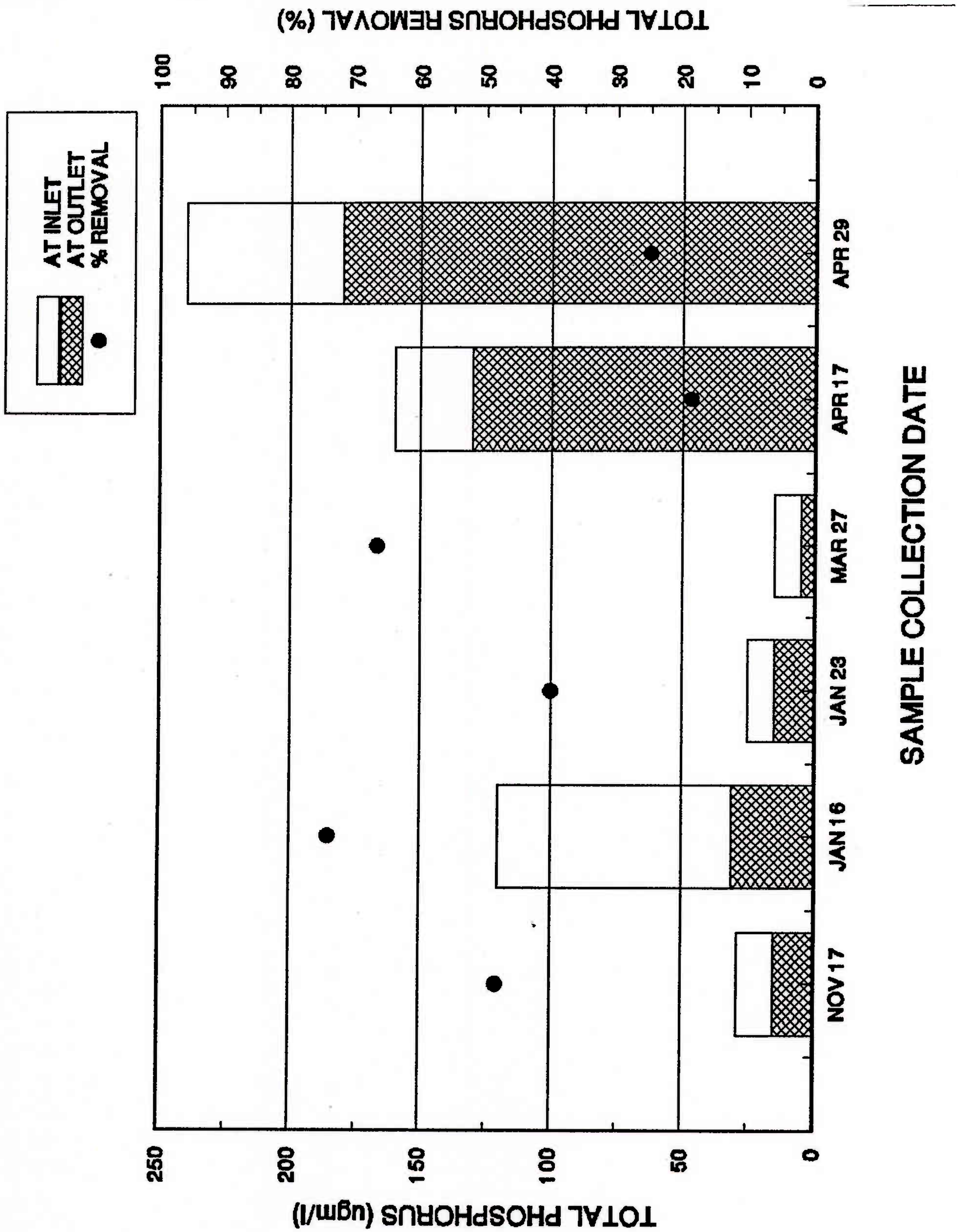

Figure 5-19. Total Phosphorus Data, 100-Foot Length

TP removal averaged 29 percent (SD=24 percent) for the 200-foot configuration. This value includes data from the high intensity storm in August, which resulted in negative removals. Without the August storm, average TP removal would be 33 percent. The 100-foot configuration showed an average TP removal of 45 percent (SD=22 percent). This figure also included a large storm in April.

Ortho-P removals averaged zero for the 200-foot length (SD=58 percent) when the negative value for the August 9 storm was included. Excluding that value, the percent removal would average 28 percent. For the 100-foot configuration, only two storms had inflow ortho-P concentrations above the detection level. One of these two storms showed higher ortho-P values in the outflow than in the inflow (negative removal) and the other showed a removal of 41 percent. The ortho-P removal data for 200 and 100-foot swale configurations are indicated in Figures 5-20 and 5-21.

Interestingly, BAP removal for the 200-foot configuration was better than TP removal, averaging 40 percent (SD=15 percent). The 100-foot configuration also showed good BAP removal, except for the large storm of April 29, which showed a very high negative removal. Without including this event, the average removal was 72 percent, based on the other five storms. Including the April 29 storm, the average removal was negative. BAP data for the 200- and 100-foot swale configurations are shown in Figures 5-22 and 5-23. One possible source of variability in the BAP data could be due to the fact that no standard holding time has been set. To be conservative the holding time of 48 hours for ortho-P should be applied to the initial step of the test. Holding time for BAP analyses performed for this study varied between five and 34 days. Data were examined for an accompanying trend in concentration related to holding time, but none was found.

Nitrogen. Nitrogen is a common nutrient typically found in elevated levels in urban runoff. The most common sources are soil, fertilizers, animal waste, decaying vegetation, and food waste. Since nitrogen is not typically a limiting nutrient in local lakes, its control is often not as critical as phosphorus. However, nitrogen is limiting in Puget Sound, especially in local embayments. In general, nitrogen tends to be more dissolved in character than phosphorus, so its control is more difficult (Randall et al., 1982).

Nitrogen, like phosphorus, is present in water in several oxidation states. The most common are nitrate and ammonia. Nitrite (NO_2) is typically oxidized to nitrate (NO_3) in the presence of oxygen, or reduced to ammonia in the absence of oxygen, hence is usually present in low concentrations. The laboratory procedure used for this study to determine nitrogen content of the stormwater integrates the nitrate and nitrite concentrations, and reports them as one value (Method 418F, Amercian Public Health Association, 1985).

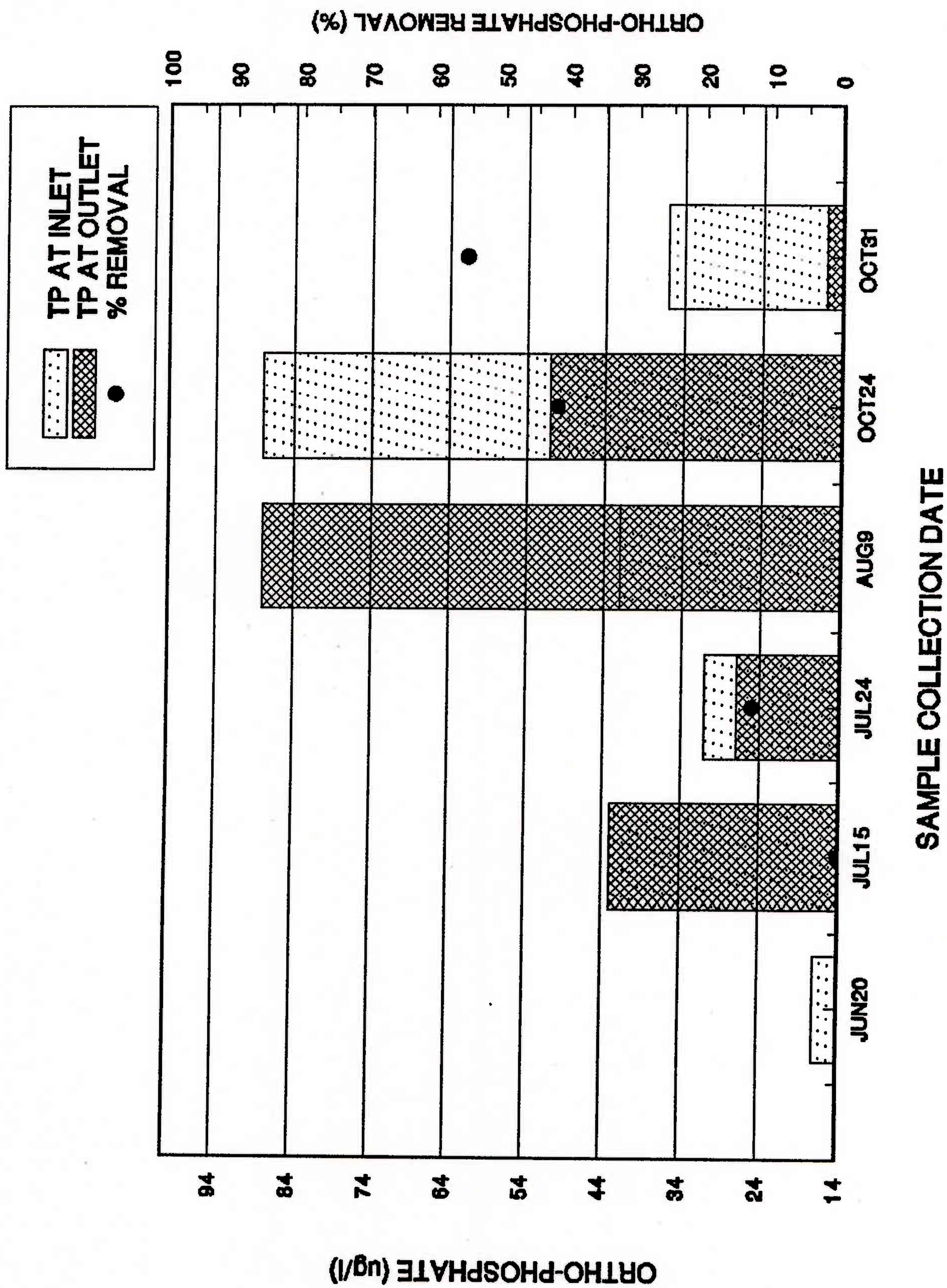

Figure 5-20. Ortho-Phosphate Data, 200-Foot Length

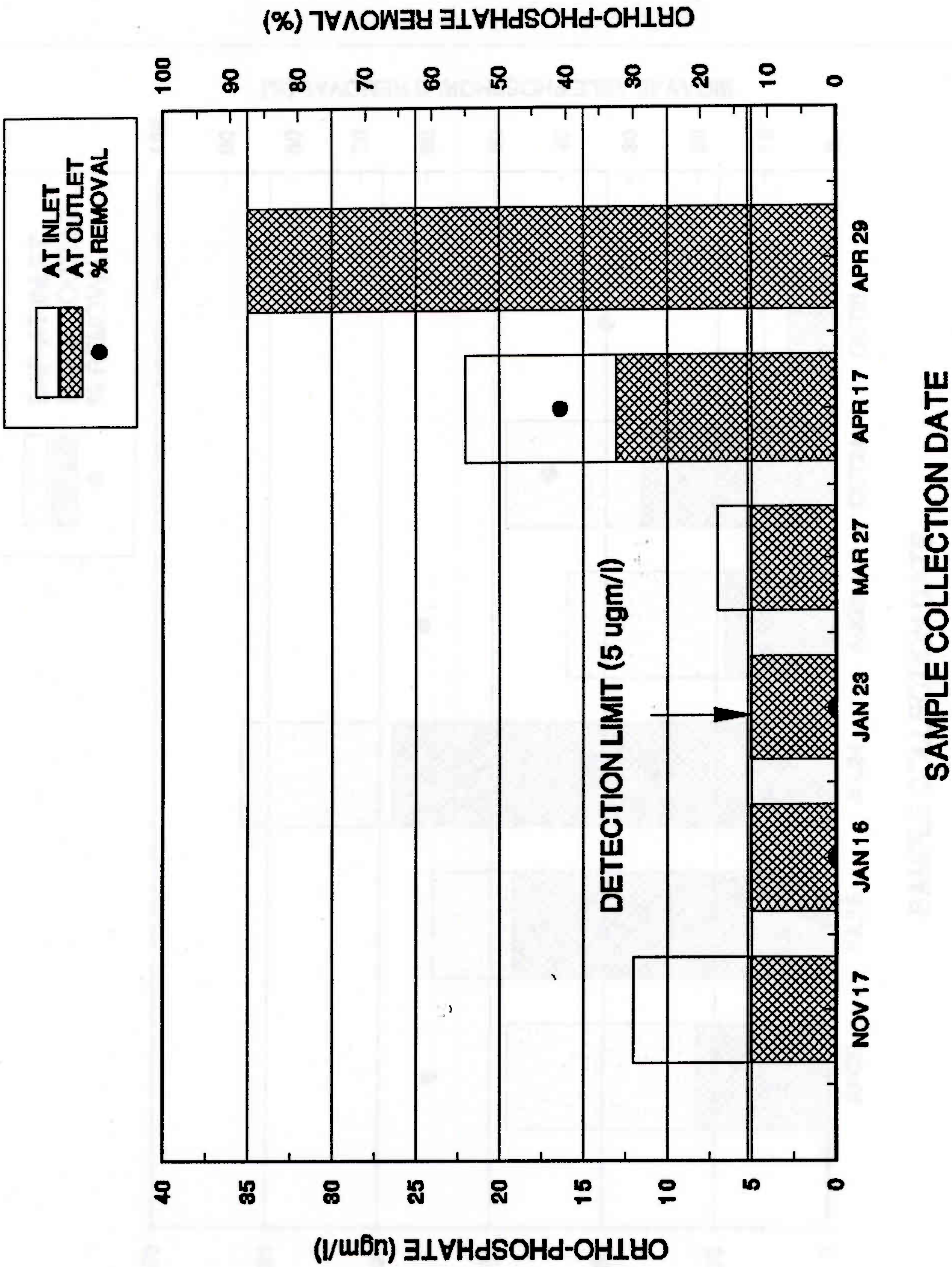

Figure 5-21. Ortho-Phosphate Data, 100-Foot Length

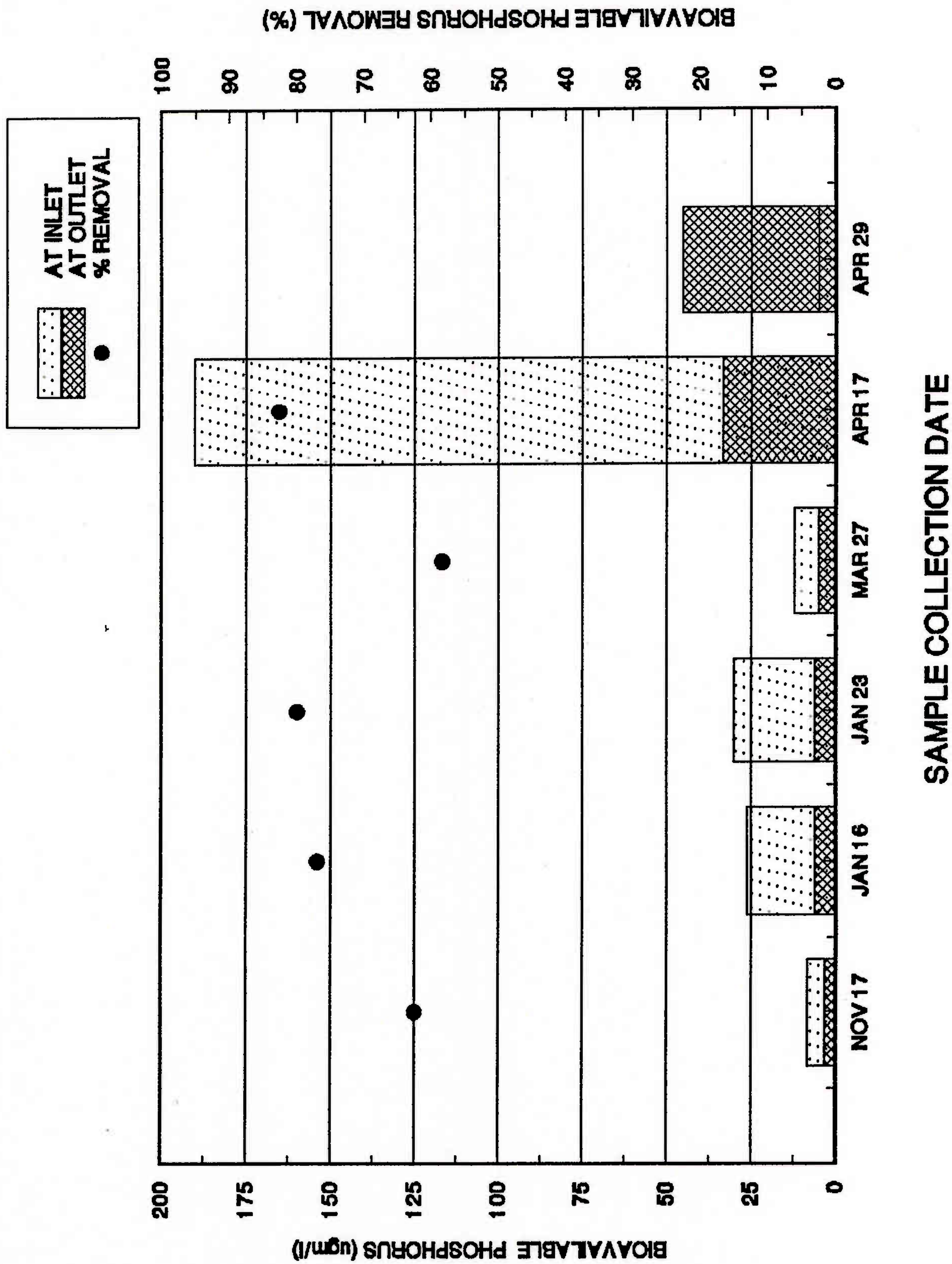

Figure 5-23. BAP Data, 100-Foot Length

Average nitrate+nitrite-N concentrations in the inflow storm samples was 0.31 mg/L, with a range of between 0.06 mg/L for very low intensity storms, to 0.86 mg/L. Removal of nitrate+nitrite-N was poor, with both length configurations showing negative removals.

Fecal Coliform Bacteria

Examination of fecal coliform bacteria in stormwater runoff is of interest for two reasons: To identify illicit sanitary sewer connections to storm drains or natural waters, and to judge suitability for primary contact recreation and shellfish culture. Sources of coliform group bacteria in stormwater may consist of both human and animals feces. Interpretation of fecal coliform data must consider the sanitary conditions surrounding the sampling source (American Public Health Association, 1985).

Since fecal coliform testing must begin within 30 hours (and preferably 6 hours) of sample collection, storms collected just prior to weekends could not be tested without exceeding holding times. Of the 16 events sampled, 14 were tested for fecal coliforms. For those storms, only six samples indicated removal of fecal coliform bacteria (removal capacity ranged between 34 percent to 85 percent). The remaining eight samples indicated increased concentration of fecal coliform bacteria at the outlets of the 200- and 100-foot length swales. The swale studied is adjacent to a major arterial and near a city park. It was often observed that people walked their dogs in and around the swale. These animal feces could be a major external source of fecal coliform bacterial loading in the swale.

In addition, some of the coliform bacteria may have multiplied on the swale bottom and on the wooden flumes. Unexpected increase of coliform bacterial densities in water are often observed due to multiplication of the bacteria (Falter, personal communication). It seems highly likely then, that the increased concentration of fecal coliform bacteria is due to animal feces and bacteria multiplication within the swale.

DISCUSSION

In general, the pollutant concentrations at the inflow were relatively low when compared to urban runoff from the City of Seattle. However, the data are similar to runoff from low to moderate density Seattle neighborhoods with the exception of lead values which were lower than the Seattle data, and total suspended solids, which were higher (Table 5-5). Declining lead values are seen in many studies, as well as in Puget Sound sediment profiles, mainly because of the dramatic reduction in the use of leaded gasolines.

Table 5-5. Comparison with 1989 Area Runoff						
	Seattle, 1989*			Combined, 48th Avenue W Swale		
	Low/Medium Density			Inflow		
Parameter	Average Concentration	% Dissolved	Number > DL	Average Concentration	% Dissolved	Number > DL
Cu (mg/L)	0.017	53%	9 of 10	0.013	38%	9 of 12
Pb (mg/L)	0.042	12%	9 of 10	0.021	23%	11 of 12
Zn (mg/L)	0.096	52%	9 of 10	0.1	31%	12 of 12
TSS (mg/L)	36		10 of 10	112		12 of 12
	Mountalke Terrace Swale (48th Avenue W)					
	200-foot Configuration Inflow			100-foot Configuration Inflow		
Parameter	Average Concentration	% Dissolved	Number > DL	Average Concentration	% Dissolved	Number > DL
Cu (mg/L)	0.02	82%	3 of 6	0.009	31%	6 of 6
Pb (mg/L)	0.02	33%	5 of 6	0.016	16%	6 of 6
Zn (mg/L)	0.11	49%	6 of 6	0.09	13%	6 of 6
TSS (mg/L)	95		6 of 6	128		6 of 6

DL = Detection limit
*Source: Merrill, S.A., Brown and Caldwell, May 16, 1989.
Letter to Claudia Corson, Seattle Drainage and Wastewater Utility, Seattle, WA
(Sample locations: Seaview, 8th Ave N.W, and Woodbine)
Note: pH was not measured in Mountlake Terrace, but stormwater runoff in the Seattle area was found by Prych and Ebbert (1986) to average 6.7 for over 100 samples.

Because stormwater samples for the two swale configurations were collected in different seasons, differences in both loading and treatment effectiveness due to grass vigor and differing storm characteristics may have occurred. Despite these confounding factors, some general patterns emerge about swale pollutant removal capabilities.

First, it is clear that solids were effectively removed by the study swale. Total suspended solids removal averaged 83 percent for the 200-foot configuration and 60 percent for the 100-foot configuration, including the higher intensity events sampled. Turbidity removal was also good, and averaging about 65 percent for the longer swale and 60 percent for the shorter configuration.

On the other hand, the swale performance was less dependable for dissolved nutrients. Despite three events showing positive removals for ortho-P, average removal was negative for both length configurations. The same pattern was true for nitrate+nitrite-N, which showed positive removal for one storm, but negative removals on average. It is possible that nitrification of ammonia to produce nitrate-N was occurring either during or between storms. Thus the nitrate-N concentrations could have increased while total N load may possibly have decreased overall.

The nutrients that are more particulate in character such as P showed intermediate removal, with BAP removal appearing to be more effective overall than TP removal. BAP removal averaged 40 percent (SD=15 percent) for the 200-foot swale, and if the one large negative value is ignored, 72 percent for the remaining 5 storms for the 100-foot configuration. However, if the one storm producing a high negative value were included, average BAP removal became negative. TP removals averaged 29 percent (SD=24 percent) and 45 percent (SD=22 percent) for the two swale configurations. No negative removal values were seen for TP. Although it appears that removal is better for BAP than for TP, the confidence intervals overlap. Considering the reliability of the estimate then, the two nutrient forms cannot be said with certainty to be removed differently.

Metal removal is more difficult to interpret since lead and copper were frequently near the level of detection. Overall, better removal of total (non-dissolved) metals was seen for those with a more pronounced particulate character. (see Table 5-4 for data on the percent dissolved metals for each storm event). For the 200-foot configuration, the most reliable data were collected for total zinc (Zn), iron (Fe) and aluminum (Al). Zinc and aluminum showed 63 percent removal (SD=15 percent and 16.6 percent), while iron showed 72 percent removal (SD=9 percent).

Although total lead (Pb) removals could be figured no more accurately than greater than 67 percent (SD 17 percent), it is likely that if lower detection limits could have been achieved, higher removals would have been revealed. Based the measured particulate character of the metal, atomic valence states and molecular weight, iron was judged to be a fairly good surrogate for lead, though somewhat lighter (molecular weight 56 rather than 106 for lead). Since iron removal averaged 72 percent, it is likely that lead removals would have been in this range also, had lower levels of quantitation been possible.

Total copper showed the poorest removal, but still averaged greater than 46 percent for the longer swale configuration. Since copper is the least particulate in character of the metals studied (82 percent was dissolved in the six storm inflows, or 18 percent particulate), it is understandable that pollutant removals would be poorer. However, since only two samples had outflow values above the detection level, little can be said with reliability. It was hoped that aluminum would be a good surrogate for copper, but data on filtered samples shows that aluminum is much more particulate in character than copper, with only 15 percent being dissolved. Thus the relatively high removals seen for aluminum could not be considered indicative of copper removal.

Dissolved metal data indicated positive removals for zinc and aluminum in some cases, though variability was high. Average dissolved zinc removal for the 200-foot configuration was 30 percent, while average aluminum removal was slightly negative. Dissolved copper and iron removals were negative, on average. Removals for the 100-foot configuration were poorer. Again, data were very near or below the level of detection much of the time, making conclusions about percent removal difficult to determine with confidence. As a general conclusion, though, it can be said that removal of dissolved metals was not as high and much more variable than the removal of total metals.

Dissolved metal concentrations in the swale outflow samples were compared to State water quality standards (Chapter 173-201 WAC). A hardness value of 17 mg/L, measured in the outflow for the October 31, 1991 storm event, was used to calculate the standards (see Table 5-4). Dissolved lead in outflow samples was below the calculated standard for one-hour exposure for the eight storms which had a sufficiently low detection levels. (For the other four storms, detection levels were too high to make any meaningful comparison.) For dissolved copper, outflow concentrations exceeded the calculated one hour standard four times for the 200-foot configuration and once for the 100-foot configuration. Dissolved zinc in the outflow samples exceeded the calculated water quality standards for six of the twelve storm events measured, though two of those values were qualified as uncertain.

These results indicate that, even after biofiltration, slightly more than a three-fold dilution for zinc and a five-fold dilution for copper would be necessary to meet water quality standards, considering only the dissolved metal concentrations. If total metal concentrations are used, four-fold and six-fold dilutions for zinc and copper, respectively, would be required to meet standards.

Oil and grease removals were good, averaging 75 percent for the longer configuration and 49 percent for the shorter configuration. TPH removal was very similar to oil and grease removals for the 200-foot configuration. Entrapment of the oil in the grass is the most likely explanation for the good removals seen.

Effect of Swale Configuration on Pollutant Removal

The effect of swale configuration will be investigated only for those parameters for which high removals were achieved in the 200-foot configuration. These include total suspended solids, turbidity, total phosphorus, bio-available phosphorus and the metals zinc, copper, iron (as a surrogate for lead) and aluminum. Both visual observations of the swale during and after storms as well as statistical analysis will be used. In addition, a attempt was made to find a functional relationship between pollutant removal effectiveness and residence time.

However, before data analysis is presented, background on storm and swale condition differences between the two sets of data will be discussed. Differences in storm characteristics and information on sediment deposition, scouring, and mowing are presented below.

Average storm characteristics for the two swale configurations are summarized below. For the 100-foot configuration, data for both the entire sample of six events and the two more intensive April storms are presented.

Storm Data	200-foot Configuration Average of all Storms	100-foot Configuration Average of all Storms	April Storms
Number of storms	6	6	2
Average duration (hrs)	5	5.8	5.0
Average rainfall (inches)	0.42	0.57	5.0
Average flow (cfs)	0.20	0.12	0.18
Average maximum flow	0.56	0.38	0.61

Storms for the 100-foot configuration tended on average to be longer and produce more rainfall than for the 200-foot configuration. However, since flows were split approximately in half for the 100-foot configuration (to provide equivalent treatment area based on $Q=V * A$), the average flow through the swale was about half that through the 200-foot configuration. The average peak flows through the swale were, however, reduced by less than half due to the effect of the two April storms which had relatively high peaks. When maximum flows are averaged without the April storms, peak flow was slightly less than half that for the 200-foot configuration, or 0.26 cfs.

The two spring storms referred to above also carried a fine black silt into the swale. This silt was of unknown origin, and settled out in the upper portion of the swale. About 20 to 30 feet of the upper swale was affected by pronounced siltation after the last event in April. Some of this material was also transported through the swale to the downstream flume. Although field staff routinely cleaned the flume between events, the finer sediment probably remained in suspension in the flume during the storm events. The water quality data for these events reflected the influence of this fine silt.

Sedimentation was also observed during storms for the 200-foot configuration test, but was not as pronounced. The sediment appeared to remain in the swale, and was not noticeably carried into the outflow flume. The sediment deposited did not appear to be as fine as that carried in the April storms for the 100-foot configuration.

An additional problem, that of scouring, was experienced after the large August 1991 storm during studies for the 200-foot configuration. An H-flume was required to allow for adequate flow measurement, as mentioned previously. However, the flume also had the effect of concentrating the water into a very narrow opening before discharge to the swale. This caused scouring of the swale bottom in the upper portion of the swale. The area was reseeded and grass plugs planted. By late August, fairly good grass cover was again established, but it was still visibly less dense than in the lower swale. This problem was unique to the study situation and should not be a concern where flows can be introduced through a larger opening.

The swale was mowed only twice during the study; once in June 1991 when the grass was about 12 inches, and again in October, before the second Manning's n experimental measurement.

As mentioned in Section 2, after forming the hypothesis of testing equal treatment areas by adjusting the flow for the 100-foot configuration, it was found that reducing swale length and flow had the unintended effect of also reducing residence time.

Thus the hypothesis was altered, and instead of testing equal effective treatment areas, the experimental set-up tested the effect of the two different residence times resulting from adjusting swale length and flow. Therefore the revised working hypothesis can be stated as follows: There is a difference in treatment effectiveness for a swale having an average hydraulic residence time of approximately 9 minutes versus 4.6 minutes.

Average hydraulic residence times for various storms were calculated by dividing average wetted volume during the storm by the average flow rate through the swale. Depths for calculating wetted volume were taken from a flow/discharge curve based on depths and flow relationships measured in the swale during the Manning's n measurements (Section 6). Table 5-6 gives the residence times calculated for all storm events for both swale configurations.

Results Based on Water Chemistry Data. Difference in removals between the two swale configurations were analyzed statistically. However, because silt was carried to the outflow flume for some storms in the 100-foot configuration, poorer percent removals were seen for those storms. When averaged with storms for which good removals were seen, the variability around the average was quite high. Thus, even though the average removal was still fairly good, the standard deviation (a measure of variability) was large, making a clear distinction between the two configurations difficult to show with statistical tests.

Even so, both zinc and iron removals were significantly better for the 200-foot configuration ($p=0.02$, zinc and 0.10, iron; Student's t test). Using the

Table 5-6. Calculated Resident Time for 200- and 100-Foot Bioswale Configurations						
L (feet)	Qav (cfs)	D Average (feet)	A (square feet)	V (cubic feet)	T (seconds)	T (minutes)
187	0.03	0.02	0.09	16.77	559.04	9.32
187	0.05	0.03	0.15	27.88	557.54	9.29
187	0.03	0.02	0.09	16.77	559.04	9.32
187	0.04	0.02	0.12	22.33	558.31	9.31
187	0.06	0.03	0.18	33.4	556.74	9.28
187	0.06	0.03	0.18	33.4	556.74	9.28
187	0.16	0.09	0.47	87.48	546.78	9.11
187	0.02	0.01	0.06	11.19	559.73	9.33
187	0.4	0.20	1.09	203.89	509.72	8.50
187	0.31	0.16	0.87	162.95	525.65	8.76
187	0.21	0.11	0.61	113.51	540.53	9.01
187	0.10	0.06	0.30	55.32	553.18	9.22
90	0.07	0.04	0.21	18.73	267.55	4.46
90	0.04	0.02	0.12	10.75	268.70	4.48
90	0.03	0.02	0.09	8.07	269.05	4.48
90	0.05	0.03	0.15	13.42	268.34	4.47
90	0.21	0.11	0.61	54.63	260.15	4.34
90	0.25	0.13	0.72	64.37	257.46	4.29
90	0.11	0.06	0.32	29.23	265.76	4.43

nonparametric Wilcoxin Rank test, no significant difference between the two configurations could be established for either zinc or iron.

Due to the high variability, however, TSS, turbidity, and phosphorus data cannot be shown to have statistically higher removals for the 200-foot configuration using either parametric or nonparametric statistical tests. In order to overcome the effects of variability, the number of storms sampled would need to have been doubled from twelve (six for each configuration) to about 24. Table 5-7 shows results of the statistical tests and approximate p values.

Results Based On Visual Observations. Overall, impressions of observers were that the shorter configuration failed to perform well during high discharge conditions. Even with the split flow, poorer overall performance was observed during the two April storms. During these storms, a fine sediment was deposited in the upper portion of the swale and carried through the swale to the outflow flume. Since sediment was spread throughout most of the upper swale bottom, poor flow

Table 5-7. Differences in Pollutant Removal for 200- and 100-Foot Swale Configurations								
	200 ft			100 ft			t*	p Value
Parameter	Average %	n Value	Standard Deviation	Average %	n Value	Standard Deviation		
TSS	83	6	9	60	6	44	1.3	0.2
Turbidity	65	6	19	60	6	19	0.5	>0.5
TP	29	6	24	45	6	22	1.2	>0.2
BAP	40	6	15	72	5			
Total Cu	46	2	15	2	5	76	1.2	>0.2
Total Pb	67	3	17	15	5	91	1.2	>0.2
Total Zn	63	6	15	16	6	58	2.7	0.02
Total Fe	72	6	9	5	6	88	1.9	0.1
Total Al	63	6	17	16	6	78	1.4	0.2

*Student's t test statistic—10 degrees freedom
Critical t = 1.81 (t values > 1.81 are statistically significant at the 0.05 level of significance)

spreading was not believed to be a major problem. However, short circuiting due to higher velocities along the edge of the swale was likely, based on results of the dye test done during the Manning's n studies (see Section 6). It is not known with certainty, however, whether the200-foot configuration would have performed better given the fine sediment loading problem and intensities experienced in the April storms.

Performance Versus Residence Time. A functional relationship between average hydraulic residence time and pollutant removals were plotted. One possible hypothetical relationship is suggested in Figure 5-24. Only data for iron and aluminum were evaluated since they had the most complete data sets. The ranges of the average hydraulic residence time for the storms were 8.3 to 9.5 minutes (average 9.3 minutes) for the 200-foot configuration, and 4.3 to 5.6 minutes (average=4.6 minutes) for the 100-foot swale configuration. Because of this narrow range of hydraulic residence time, there are not sufficient data to establish a correlation within an acceptable confidence limit.

The intent of the attempted correlation was to establish a swale design criterion based on optimum hydraulic residence time for efficient pollutant removal. It is expected that the longer the hydraulic residence time the higher will be the pollutant removal, and the relationship is anticipated to be exponential, based on trends observed by Wang et al. (1981). It would be worthwhile investigating the relationship between hydraulic residence time and pollutant

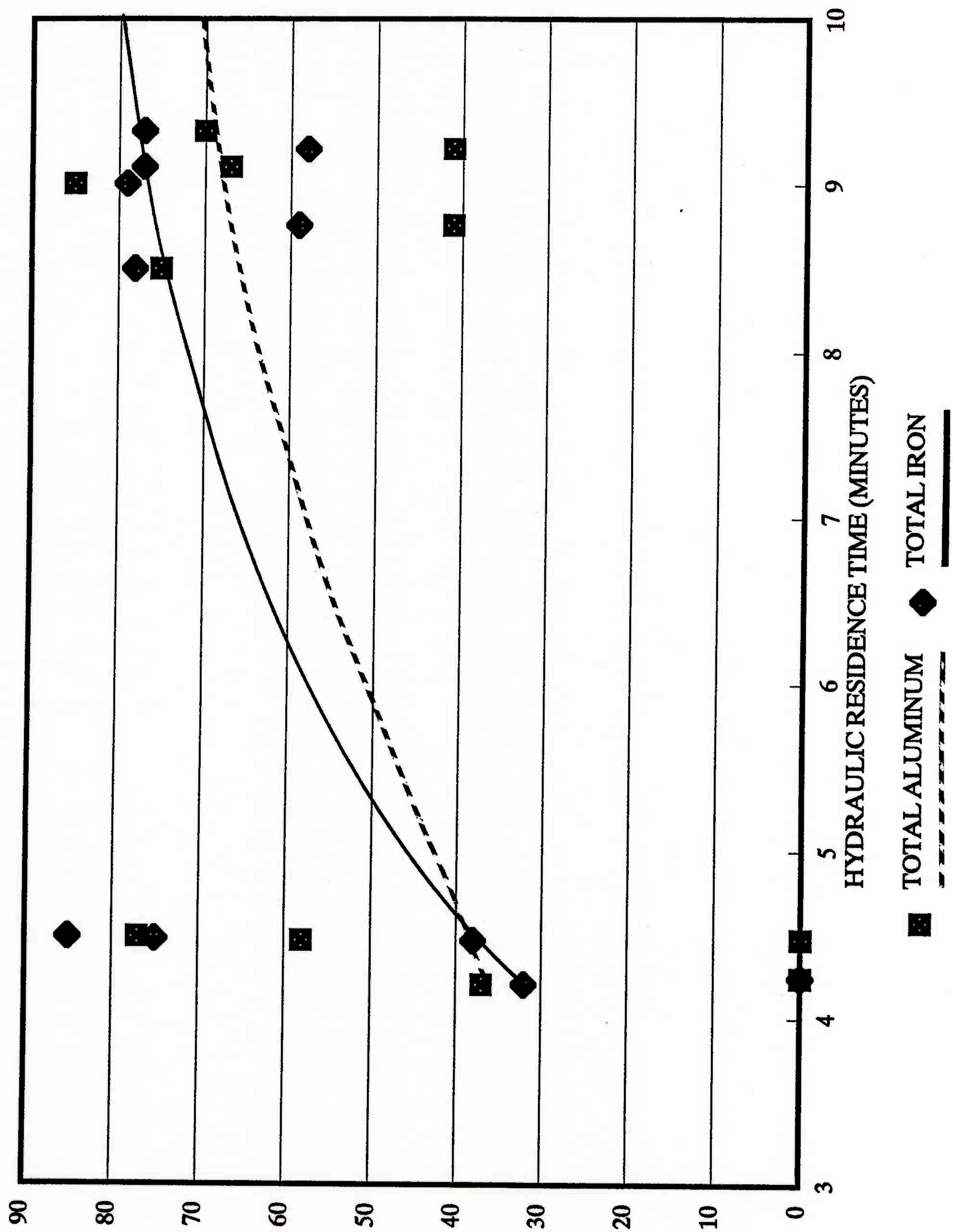

Figure 5-24. Hydraulic Residence Time Versus Metals Removal

removal in greater detail because it would provide a sound, conservative, but flexible design basis for biofiltration swale design.

Based on the limited observations this study was able to make, it appears that a 4 to 5 minute residence time is near the minimum required for effective pollutant removal, but this cannot be said with confidence. A 9-minute residence time, on the other hand, appears to be adequate to assure good pollutant removal, not only for iron and aluminum, but for other constituents as well, based on observed removals given previously.

In investigating filter strips for the treatment of wastewater, a detention time of 20 minutes was found to remove 85 percent of the total suspended solids (USEPA, 1980). However, because of the differences between wastewater and stormwater in terms of particle size and loading, and because TSS removals of about 83 percent were observed for residence times of about 9 minutes, it is suggested that a residence time of 9 minutes is sufficient to assure good pollutant removals. A minimum hydraulic residence time cannot be given with certainty, although it can be said that with residence times of about 4.5 minutes, deterioration in performance is likely, especially during larger storms. Depending on the land use and expected pollutant loading, residence time should be adjusted to provide sufficienct time for sedimentation and filtration.

In summary, the performance of the two swale configurations could be shown to be statistically different only for zinc and iron removals. The findings with zinc and iron suggest that a 4 to 5 minute residence time is less effective than a 9-minute residence time. In addition, the observations that a sizable area of the shorter configuration was negatively affected by silt accumulation during two spring storms, and that silt was carried through the swale to the outflow, perhaps because of short circuiting, also suggest that it was less effective. In addition to the difference in detention times, the two swale configurations were also different in length, total flow and water depth. These variables may have contributed to the poorer performance seen during higher intensity April storms. It is also noted that the shorter configuration was used in the winter and spring months, while the longer configuration was used during the summer and fall. This seasonal difference may also contribute to differences in performance and resilience.

CONCLUSIONS

The following conclusions can be drawn from the swale performance data collected as part of this study.

- Biofiltration swales designed according the Phase I criteria (Horner, 1988) can be expected to consistently remove particulate pollutants such as total suspended solids, turbidity, and metals of largely particulate character, such as lead and zinc. Materials that adhere to the grass surfaces, such as oil and grease and TPH, are also effectively removed.

- Nutrients are removed to varying degrees, with best removals seen for bio-available phosphorus (40 percent), followed by total phosphorus (29 percent). Poor or negative removals were seen for dissolved nutrients, such as ortho-P and nitrate+nitrite-N.
- Dissolved metal removal was seen for zinc and aluminum, though the magnitude of removal was on average low and variability high. Dissolved zinc removal averaged 30 percent for the 200-foot configuration, with a range from 87 percent to negative. Dissolved copper, iron, and aluminum removals were negative on average, although for some events positive removals were seen. Dissolved lead was always below the detection level.
- The removal of fecal coliform bacteria was highly variable. Some of the data show good removals, while other storms produced elevated concentrations in the outflow. These increased loadings were probably caused by external sources (such as pet wastes) and bacterial multiplication on the swale bottom and on the wooden flume bottom.
- A hydraulic residence time of about 9 minutes (at the 200-foot length configuration) produced good removal of particulate pollutants including metals, oil and grease, and TPH. This residence time is, then, recommended as adequate to ensure pollutant removal performance of about 80 percent TSS. Higher residence times are recommended if higher pollutant removal levels are desired.
- When the hydraulic residence time was reduced to 4.6 minutes (at the 100-foot length configuration) visual observations and performance data for zinc and iron suggest that performance was poorer than for the 9-minute residence time, 200-foot configuration. Because of the high variance in the average removals for the 100-foot configuration, removal data for most parameters could not be shown to be statistically different. However, it is suggested that a residence time of 4 to 5 minutes is not adequate to assure good pollutant removals, particularly for storms with significant rainfall peaks. More work is needed before a residence time of less than 9 minutes can be recommended with confidence as adequate for biofiltration swale design.